THE GEOLOGICAL SURVEY OF WYOMING
HORACE D. THOMAS, STATE GEOLOGIST

BULLETIN NO. 37

GEOLOGY OF BENTONITE DEPOSITS NEAR CASPER, NATRONA COUNTY, WYOMING

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ILLUSTRATIONS

TABLES

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by

Gabriel Dengo

ABSTRACT

Bentonite occurs in the Casper area, Natrona County, Wyoming, as beds in the Mowry, Frontier and Steele formations, all of Upper Cretaceous age. The most important deposits are described and are illustrated by geological and topographic maps. Results of petrographic examinations and of tests on physical properties of the bentonites are presented. Economic features of the deposits are discussed and estimates of available tonnages of bentonite are given.

INTRODUCTION

Wyoming ranks first among bentonite-producing states and bentonite mining and processing constitute the most important nonmetallic mineral industry in the State. In general, the Wyoming bentonite industry has centered around the Black Hills uplift, in Crook and Weston counties, but bentonite occurs at many other places in the eastern half of the State.

Study of the bentonite deposits of the Casper area, Natrona County, (Fig. 1) was undertaken to obtain data which would be useful in their possible commercial exploitation. None of the deposits in the area had been exploited when the field study was made, but subsequently a bentonite processing plant has been established in Casper.

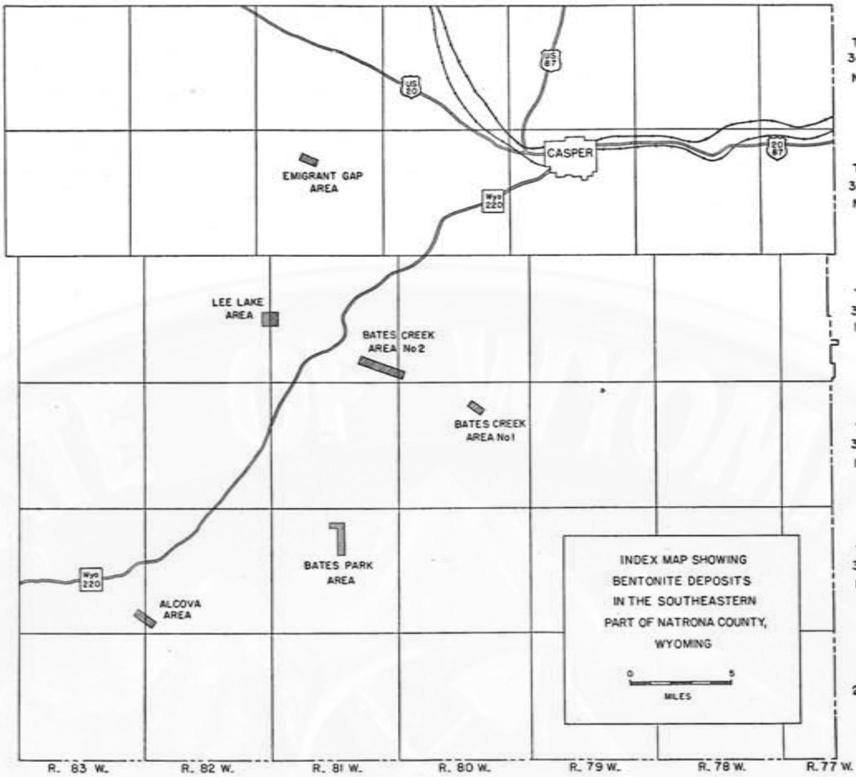

Figure 1. Index map showing bentonite deposits in the southeastern part of Natrona County, Wyoming.

Data on the geology and topography of individual deposits and on petrographic features and quality of the bentonite are presented. Detailed maps were made of the most important deposits in the vicinity of Casper, in the southeastern part of Natrona County. Other deposits, such as those near Midwest and Natrona, were examined and sampled, but not mapped.

Mapping with plane table and alidade was carried on in the field from July 30 to September 24, 1945. Sampling was done by trenching across bentonite beds so that fresh composite material could be taken. The physical tests of samples were made by the staff of the University of Wyoming Natural Resources Research Institute. Petrographic studies were made by the writer following the usual methods of observation of thin sections and crushed fragments.

The author wishes to express his appreciation to Dr. H. D. Thomas, State Geologist, for directing the work and for making it possible through the financial support given by the Geological Survey of Wyoming; to Dr. S. H. Knight, Chairman of the Department of Geology of the University of Wyoming, for advice; to Dr. A. F. Hagner, of the same Department, for reading the manuscript and for suggestions; to Dr. H. G. Fisk, Director of the Natural Resources Research Institute, for testing the bentonite samples; and to Mr. Napoleon Bazo for his assistance as instrument man during the field work.

NATURE OF BENTONITE

Bentonite is a light-colored sedimentary clay, with a high colloid content, which may possess the property of swelling to several times the original volume when wet. Because of these physical properties, bentonite has many uses. The chief uses of the swelling type are as an ingredient of mudladen fluids used in rotary-drilled wells and as a binder for sands used in foundry molds. Detailed information on the uses of bentonite has been given recently by the University of Wyoming Natural Resources Research Institute (2).*

To be classed as bentonite, a clay must consist of at least 75 per cent of the clay minerals montmorillonite or beidellite. Montmorillonite is the chief constituent of the bentonites described in this paper. The montmorillonite group of clay minerals is made up of the mineral species montmorillonite, beidellite, nontronite and saponite. Kerr (11:268) gives the formula for montmorillonite as $(Mg\ Ca)O \cdot 5SiO_2 \cdot Al_2O_3 \cdot nH_2O$. Winchell (19:510) considers the group as an isomorphous series consisting of four end members. Information on the mineralogy of the group and on clay minerals in general can be obtained from the works of Grim (3) Hendricks (9), and Ross and Hendricks (15).

In hand specimens, bentonite from the Casper area is a light-colored, usually white to cream, fine-grained rock with subconchoidal fracture, which varies in structure from massive to flaky or shaly. When fresh the rock is soft and has a greasy feel. Weathered material is harder, darker, and more highly fractured than fresh specimens because of the successive absorption and loss of water which causes changes in volume.

Bentonites which absorb water, increasing their volume several times, are classified as swelling type bentonites. All the deposits described here are of the swelling type. This property, according to Bechtner (1:131-132), is attributable to the three following factors: 1) water penetrates the crystal lattice of the montmorillonite, 2) a film of water is formed around individual particles pushing them apart, and 3) all the particles have negative polarity and repulse each other.

The swelling property varies with the amount of grit contained in the bentonite, those free from grit swelling more readily. The grit consists of grains of different minerals and the following were found in samples from the Casper area: orthoclase, plagioclase, biotite, muscovite, quartz, zircon, glass, magnetite, and selenite.

Many of the outcrops of bentonite examined are characterized by an abundance of selenite crystals ranging in size from small fibers to crystals three inches in length.

ORIGIN OF BENTONITE

Since the work of Hewett (10) it has been known that bentonite is a product of alteration of volcanic rocks such as ash and acidic lavas. The environment in which the ash was deposited and the conditions under which it was altered seem to differ for different deposits (15:66). The bentonites with which this paper treats originated by alteration of volcanic ash that was deposited in the shallow Cretaceous sea of the Western Interior (16:156). Marine fossils, such

*In citations to references, the first figure indicates the number in the list of references at the end of this paper; the second figures indicate pages.

as Radiolaria and fish scales which are common in the Mowry shale, and marine mollusks which are common in the Frontier and Steele formations, indicate that the rocks containing them were deposited in sea waters. The presence of abundant fish scales and Radiolaria in the Mowry shale may suggest deep-sea sedimentation, as has been pointed out by Rubey (16:156). On the other hand, the presence of other kinds of fossils such as mollusks and bone fragments, and the lithologic characteristics of the rocks, indicate shallow sedimentation. The lithology of the formations under consideration gives the best evidence of shallow-water deposition of these sediments. The alternation of sandstone and shale beds, the well-sorted nature of the sandstones, some of which show ripple-marks, and the great thickness of some of the shale units, such as the Steele shale, suggest shallow-water deposition.

The ash deposits were believed by Rubey (16:160) to have been rhyolitic in composition, but petrographic observations of Casper bentonites indicate a less acidic character of the ash. Free silica exists in small quantities and ferromagnesian minerals are scarce. The plagioclase is mostly andesine. These characteristics indicate a composition of the ash similar to a latite, which seems to be the type of glass that alters most readily to bentonite (15:65).

In 1928 Ross and associates (14:185-186) considered that alteration of the ash involved mostly hydration and solution of glass particles, aided probably by the presence of chlorides and bicarbonates. In a recent paper Ross and Hendricks (15:60) state that "Experiments on synthesis indicate that the formation of montmorillonite is favored by alkaline conditions or by the presence of salts of alkalies and alkaline earths, in particular by magnesium . . Some bentonites are known to contain more magnesium than the glass from which they were derived, and this may have been supplied either by marine waters, if alteration occurred in the ocean, or by ground waters, if alteration took place after burial." In considering the Casper bentonites, marine waters seem to have been the environment of alteration. Marine waters are slightly alkaline and therefore provide an appropriate environment for the formation of montmorillonite, supplying also the necessary magnesium.

Alteration of the volcanic ash seems to have been a diagenetic process which occurred in place before the sediments were lithified and exposed to the atmosphere. Diagenesis involved mainly hydration of the original ash, solution and loss of some silica, and exchange of bases between the environment of deposition and the altered ash (7:260), producing a complete change of the amorphous ash into crystalline montmorillonite. As a final product of diagenesis selenite was deposited along bedding planes, indicating that the connate water left in the rocks was rich in calcium sulphate. Field and microscopic observations indicate that the selenite formed later than the bentonite and that its original occurrence along bedding planes has been somewhat changed by weathering, since it is in the weathered portions of the outcrops that the largest selenite crystals are found.

GEOLOGIC OCCURRENCE

The bentonite deposits of central Wyoming occur as beds in sedimentary rocks of Upper Cretaceous age. These rocks consist of a succession of thick shales and relatively thin sandstones approximately 10,000 feet thick. Table I gives the names of the Cretaceous formations.

TABLE I

CRETACEOUS FORMATIONS OF CENTRAL WYOMING

	Formation	Character	Approximate Thickness in Feet
Cretaceous rocks	Lance	Sandstones and shale.	3,200
	Lewis	Sandstones and shale.	1,400
	Mesaverde	Sandstone, mainly.	850
	Steele	Dark shale: Shannon sandstone member near middle; bentonite.	2,300
	Niobrara	Limy shale.	950
	Frontier	Sandstones, shale, bentonite.	900
	Mowry	Siliceous shale, bentonite.	250
	Muddy	Sandstone.	10
	Thermopolis	Dark shale.	200
	Cloverly	Sandstones and shale.	100

Bentonite occurs mainly in the Mowry, Frontier and Steele formations. The beds range in thickness from a few inches to as much as 9 feet, but only those thick enough to be of possible commercial interest are considered here.

At the top of the Mowry, in the Casper area, is a persistent bentonite bed of fairly uniform thickness. A bed lying at the top of the Mowry in the Black Hills region has been called the Clay Spur bentonite bed (17:4). The Mowry consists mainly of siliceous shale with several thin bentonite seams at various stratigraphic levels. Under each seam the shale is harder and more siliceous than elsewhere in the formation. This fact was noticed and studied by Rubey (16) who believed that the presence of bentonite is only indirectly related to the hardness of the shale, since both have practically the same silica content. The hard shale which underlies the bentonite bed at the top of the formation near Casper is fine-grained and equigranular, and consists mostly of angular plagioclase and quartz cemented by argillaceous material and carbonate. Minor constituents are, in approximate order of abundance, radiolarian fragments, carbonaceous matter, magnetite, biotite, orthoclase, tourmaline, and questionable lithic fragments.

In the Frontier formation of the Casper area there are two beds of bentonite thick enough to warrant consideration. They are interbedded with shales, and although not as noticeable as in the Mowry, the shales are harder just below the bentonite beds. The two bentonite beds in the Frontier are in the upper part of the lower half.

In the Steele shale, bentonite beds occur associated with the shales above the Shannon sandstone member. The shales which underlie them are not harder than the other shales in the formation.

For the purpose of this paper the bentonite beds are designated by the names of the formations to which they belong, that is, Mowry bentonite, Frontier bentonite, and Steele bentonite. Where two beds are present in the same formation, the adjectives lower and upper are used to distinguish them.

The deposits studied are mostly Mowry bentonite. One area described contains both Mowry and Frontier bentonites. Two deposits discussed are Steele bentonite. Additional information on the geology is given in the individual descriptions of deposits.

DESCRIPTION OF DEPOSITS

Where bentonite crops out, its economic possibilities are controlled mainly by two factors, 1) attitude of the beds, and 2) degree of dissection of the overlying rocks. The attitude of beds is of major importance since high angles of dip mean, at most places, thick overburden. Degree of dissection of the rocks above the bentonite is important because if it is considerable, the amount of overburden remaining above the bentonite is small. In some places where the rocks dip at fairly low angles, the deposits are of little value because the overlying rocks have been only partly removed by erosion. It is estimated that, in order to consider a bentonite deposit of commercial importance, the ratio between the thickness of the bentonite bed and that of the overburden should not be greater than 1:3. Another factor of less importance bearing on commercial possibilities is the occurrence in some places of alluvial material covering the bentonite beds.

Taking these factors into consideration, after the observation of bentonite outcrops at different places within the Casper area, it was decided to map only those localities where the thickness and attitude of bentonite and the degree of dissection of overlying rocks make the deposits of possible commercial value (Fig. 1). The only place where steeply dipping beds were mapped is the Lee Lake area.

BENTONITE IN THE MOWRY FORMATION

Emigrant Gap Area

The South Emigrant Gap anticline is an asymmetric fold which trends northwest. The southwest limb is the steeper. The Mowry bentonite bed crops out at intervals around the anticline, but only at some places on the northeast limb does it present conditions favorable for commercial exploitation.

On the north plunge of the anticline, in sec. 9, T. 33 N., R. 81 W., there is a good exposure of bentonite about 4,000 feet in length (Plate I). The bed dips from 4° to 10° NE. Bentonite is yellow and weathered on the surface. When fresh, it is light-cream colored, has a flaky structure, and is uniform throughout its thickness of 4.5 feet.

To the southeast, on the northeast flank of the anticline just north of the North Platte River, there are places where the bentonite occurs under favorable mining conditions, although over small areas. One area is in the NE 1/4 sec. 24, T. 33 N., R. 81 W., where the beds strike N. 20° W. and dip 10° E. Here bentonite is exposed on the sides of several gullies. Between the gullies the amount of overburden in relation to thickness of the bentonite exceeds the proportion of 3:1.

Another deposit is located in secs. 24 and 25, T. 33 N., R. 81 W. It is larger than the one just mentioned, but presents similar conditions. There are several gullies which cut through the Frontier shale and expose an inlier of Mowry formation and the upper bentonite bed. The amount of overburden greatly restricts the area of possible exploitation because the proportion 1:3 is again exceeded. The bentonite bed here is 4.8 feet thick and the lithologic characteristics are similar to those at the north end of the anticline. The bed strikes north-south and dips from 6° to 9° E.

On the same flank (northeast) of the anticline, but south of the North Platte River, the Mowry bentonite bed is again exposed. In the SE 1/4 sec. 31, T. 33 N., R. 80 W., bentonite is found cropping out around small Frontier shale outliers in the so-called Blue Hill deposits. In the NE 1/4 of the same section bentonite crops out around a Frontier remnant about 400 feet in width and extending north and south for 500 feet. Here the strike is N. 25° W. and the dip 9° E. The bed is 4.8 feet thick.

Mowry bentonite from the Emigrant Gap area, sec. 9, T. 33 N., R. 81 W., consists of about 90 to 95 per cent clay minerals and 5 to 10 per cent nonclay minerals. Montmorillonite is the most prevalent if not the only clay material, and occurs as fibrous aggregates in the shape of shards which have a rough parallel arrangement. The other constituents are, in approximate order o. abundance, orthoclase, biotite, plagioclase, quartz, magnetite, and zirconf The feldspars and quartz are in part replaced by montmorillonite, and some of the magnetite is weathered to hydrous iron oxide.

The Mowry bentonite at the Blue Hill deposit, sec. 31, T. 33 N., R. 80 W. is made up of 85 to 90 per cent montmorillonite and possibly other clay minerals, and 10 to 15 per cent of nonclay minerals. Montmorillonite occurs in aggregates of unoriented fibers. Most of the crystals are very small, but a few are as long as 0.2 mm. There are distinct areas of finer montmorillonite which are probably the ghosts of former grains of feldspar or glass, now completely replaced. The nonclay minerals are angular grains of plagioclase, orthoclase, biotite, and quartz, and a very small amount of magnetite and zircon. Magnetite is partly altered to limonite and the feldspars and quartz are replaced on the edges by montmorillonite. A few grains consisting of isotropic areas and montmorillonite seem to be highly replaced or altered glass.

Alcova Area

South of Alcova, on the east side of the Alcova reservoir, is an asymmetric syncline plunging southeast. The Mowry bentonite bed is exposed on both limbs of the fold. The northeastern limb is too steeply inclined to warrant exploitation. In the NE 1/4 sec. 31, T. 30 N., R. 82 W., the bentonite bed strikes N. 60° W. and dips 72° SW.

On the southwestern limb of this syncline the dips are mainly between 5° and 7° so that the bentonite outcrops have greater commercial possibilities. In some places where the surface slopes in the same direction as the dip of beds, there are wide bentonite exposures having little or no overburden.

Plate II shows parts of secs. 25 and 36, T. 30 N., R. 83 W., and sec. 31, T. 30 N., R. 82 W., where the bentonite is well exposed. From the map it can be seen that near the Alcova reservoir a thick overburden of Frontier shale covers the bentonite, which is exposed only around several hills. Following the bentonite outcrop away from the reservoir, more favorable conditions are found because the overburden becomes thinner and exposures are wider. Bentonite exposures continue toward the southeast, along the gently inclined limb of the syncline, beyond the limits of the map. These exposures are interrupted by soil and gravel-covered areas.

In the Alcova area the Mowry bentonite bed has a thickness of 5 feet. It is light-cream colored, uniform all through its thickness, and contains a small quantity of selenite crystals. Near the reservoir, bentonite outcrops are less weathered than in other places in the area.

A specimen of Mowry bentonite from sec. 36, T. 30 N., R. 83 W., contains 85 to 90 per cent montmorillonite and the remainder consists of biotite, orthoclase, plagioclase, quartz, glass, and muscovite. Montmorillonite is present in microcrystalline aggregates. Occasionally larger fibers are found, having a subparallel arrangement. Among the nonclay minerals plagioclase, orthoclase, and biotite are the most abundant. These minerals, as well as the glass and the few flakes of muscovite, show replacement effects by montmorillonite.

Bates Park Area

The Bates Park anticline is an asymmetric structure which trends northwest. The Mowry bentonite bed is exposed all around the anticline. The southwest flank is characterized by steep dips which are so high that it would not be economically possible to obtain large quantities of bentonite. On the other hand, the northeast flank has low dips. Good exposures are found in the SE 1/4 sec. 4, the SW 1/4 sec. 3, the W 1/2 sec. 10, and the NE 1/4 sec. 15, T. 30 N., R. 81 W. The best are those in section 10.

The Bates Park area was mapped for the Geological Survey of Wyoming by John R. Ellis in 1941, and part of his map is given in Fig. 2. The outcrop of bentonite at the top of the Mowry is shown. Since the map does not show topography, it gives no indication of amount of overburden. The writer observed that over a large part of the area the 1:3 ratio is not exceeded, so that mining conditions are possibly more favorable than in most of the areas described.

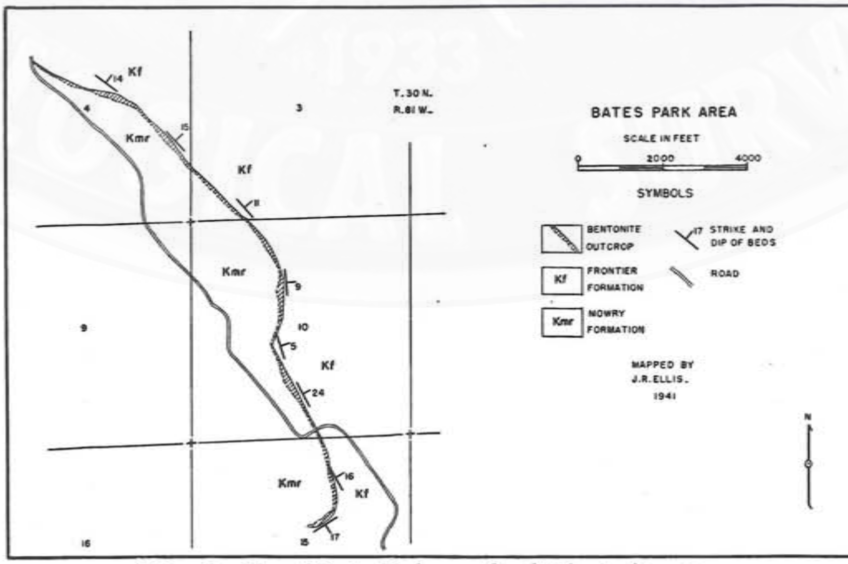

Figure 2. Map of Bates Park area showing bentonite outcrop.

The bentonite bed has a uniform thickness of 5 feet. The bentonite is cream colored, turning yellowish when weathered, and has flaky structure.

Mowry bentonite from sec. 10, T. 30 N., R. 81 W., consists of about 90 per cent montmorillonite and 10 per cent nonclay minerals. Montmorillonite occurs as a dense aggregate of small flakes, sometimes in the form of shards which are arranged in more or less parallel rows. The nonclay minerals are orthoclase, plagioclase (andesine), biotite, quartz, chalcedony, zircon, and magnetite. Replacement effects are shown at the edges of quartz and feldspar grains.

Bates Creek Area

The area bearing this name is located along the road to Medicine Bow, between Wyoming highway No. 220 and Big Red Creek. In general, the strata strike about N. 60° W. and dip gently southwest. Along the Frontier-Mowry contact there are some highly dissected areas in which the Mowry bentonite bed is well exposed. Two of these exposures have commercial possibilities, and were therefore mapped.

Bates Creek No. 1. An arbitrary name, Bates Creek No. 1, is here given to the bentonite deposits located in sec. 10, T. 31 N., R. 80 W., and shown on Fig. 3. The bentonite crops out on the slopes of several hills, but is covered either by soil or gravel in the areas between the hills. The position of the bentonite, where it is covered, can be estimated with fair accuracy by means of dip and strike data taken at the outcrops.

The dip of the strata, and thickness of the bentonite bed which is 4.8 feet, are favorable from a commercial point of view, but the amount of overburden over most of the area exceeds the 1:3 ratio.

A specimen of Mowry bentonite from this area consists of 85 per cent to 90 per cent montmorillonite and 10 to 15 per cent of other minerals. Montmorillonite is present, as in the other samples of Mowry bentonite, in fine light-yellow aggregates. The other minerals are, in order of abundance, orthoclase, plagioclase, biotite, and a few grains of quartz, limonite, and zircon. Both feldspars are replaced by montmorillonite. Plagioclase was determined to be andesine. The grains of quartz do not show any replacement effects similar to those of other specimens.

Bates Creek No. 2. The area here called Bates Creek No. 2 is located in the SW 1/4 sec. 31, T. 32 N., R. 80 W., the N 1/2 sec. 36, and the SE 1/4 sec. 35, T. 32 N., R. 81 W., as shown on Plate III. There are several outcrops of bentonite, the best ones being at the eastern end of the area mapped, that is, in the SW 1/4 sec. 31, T. 32 N., R. 80 W., in an inlier of the Mowry formation.

The overburden of Frontier shale is thick, and consequently restricts the area of possible exploitation. At the western end of the area, as shown on the map, the Frontier-Mowry contact is covered by alluvium 15 or more feet thick.

The thickness of the bentonite bed here is the same as in the Bates Creek No. 1 area, and field characteristics of the bentonite are practically the same as described for the Emigrant Gap and Alcova areas.

In general, the Bates Creek area presents good conditions as far as thickness, dip of bentonite bed, and extent of outcrops along the strike are concerned, but the extent of outcrops along the direction of dip is highly restricted by the amount of overburden.

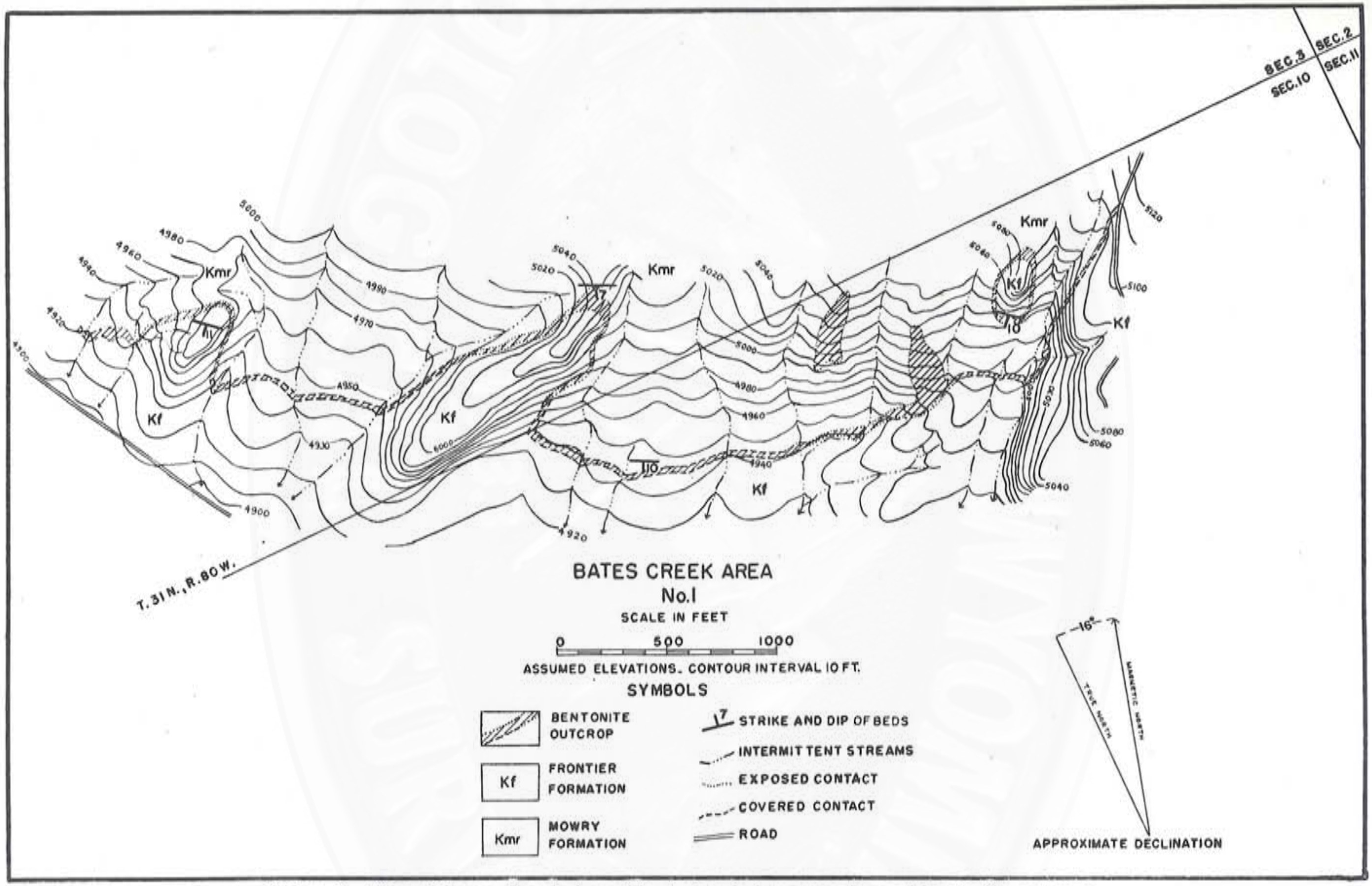

Figure 3. Map of Bates Creek Area No. 1 showing topography and bentonite outcrops.

Other Areas

Mowry bentonite is found in several other areas in the Casper region. Among them it is worthwhile to mention the deposits at Oil Mountain, Pine dome, and at the eastern end of Casper Mountain. At those places the Mowry bentonite bed is exposed and has practically the same thickness as at the other localities mentioned, that is, about 5 feet. These areas were not studied in detail, however, because in general the dips are steep.

BENTONITE IN THE FRONTIER FORMATION

Lee Lake Area

The Lee Lake area is located in secs. 13 and 24, T. 32 N., R. 82 W., and secs. 18 and 19, T. 32 N., R. 81 W., as shown on Figs. 4 and 5. Geologically, it is the western continuation of the Bates Creek region.

Three different bentonite beds are exposed; the bentonite of the Mowry formation, and two bentonite beds in the Frontier formation. Because of the complex folding and faulting of the rocks, as shown on the maps, the outcrops of Mowry and Frontier bentonites come close together.

The conditions considered above as limiting the value of the bentonite deposits are not favorable in this area. Thicknesses are adequate, but the geologic structure and amount of overburden make these deposits of little value.

The geologic structure of the area is shown in Fig. 5. The thrust fault at the north face of Casper Mountain extends westward through the region. Strata on the north side of the fault, in the downthrown block, are essentially vertical and in some places slightly overturned. The southern, or upthrown block, is folded; the main structures being two anticlines and a minor syncline.

Bentonite beds in the Mowry and Frontier are exposed on both sides of the fault. On the north side their attitude practically eliminates any possibility of commercial exploitation. On the south side, the lower dip presents a more favorable condition. The amount of overburden, however, exceeds the 1:3 ratio over most of the area.

In order to show more accurately the stratigraphic positions of the bentonite beds in the Mowry and Frontier formations, the following partial stratigraphic section was measured in the SW 1/4 sec. 18, T. 32 N., R. 81 W.

Frontier Formation	Thickness in Feet
Dark gray fissile sandy shale	Not measured
Brown massive medium-grained sandstone	6.0
Dark gray fissile shale	70.0
Upper bentonite bed (described below)	3.0
Dark gray fissile shale	7.0
Lower bentonite bed (described below)	4.5
Brown massive medium-grained sandstone	4.5
Dark gray fissile shale with layers of ferruginous concretions	71.0
Light brown coarsely laminated medium-grained sandstone with large dark brown ferruginous concretions	51.0

Comparing this section with one given by Lee (12:48-49), which was measured near the west end of Casper Mountain, the following differences are noteworthy: 1) Lee does not give the position of the bentonite beds in his section, 2) the thicknesses of the beds in the Frontier formation are different in both sections, the main difference being that the lower shale is thicker in Lee's section. This may be explained by the fact that measurements here given were taken near a fault where the bed in question, because of its incompetency, has been thinned by structural deformation. The section was measured under such in appropriate conditions because the contacts are better exposed where measured than at any other place in the Lee Lake area.

The Mowry bentonite here is 5 feet thick and presents essentially the same characteristics as at the other places described. It is white to cream-colored when fresh, and yellowish when weathered. In places it is covered by gravel.

Bentonite in the Frontier formation occurs as thin seams in the lower shale unit and as two thick beds stratigraphically higher in the section. The lower one overlies a sandstone bed. Between the sandstone and bentonite there are places where a black shale, about one inch thick, and a thin layer of gypsum are found. The bentonite bed is 3.5 feet thick and grades upward into a bentonitic shale with swelling properties, giving a total thickness of 4.5 feet. The thickness varies somewhat, being 3 feet in places. Selenite and shale are present within the bentonite, occurring probably in thin lenticular layers. The bentonite is cream-gray and, when weathered, changes to yellow. It is more weathered than that of the Mowry formation and on the surface exists mostly in a powdery condition which seems to be due not only to weathering but also to its selenite and shale content.

The upper bentonite bed of the Frontier formation is separated from the lower by 7 feet of dark gray shale. The bed is 3 feet thick, but the uppermost 10 inches is gritty and grades into the overlying shale. In some places it is as thick as 3.5 feet. It is separated from the underlying shale by 2 inches of gypsum and by a thin layer of black, apparently more siliceous, hard shale. Like the lower bed, it includes thin discontinuous layers of black shale. Its appearance in the field is the same as the lower bed, that is, yellow, powdery, and with a high selenite content.

A specimen of Frontier bentonite from the lower bed contains about 95 per cent clay minerals and 5 per cent nonclay minerals. Montmorillonite is the most abundant and probably the only clay mineral present. It occurs as fine aggregates of fibers which are arranged more or less subparallel to the bedding of the rock. It also occurs as rims around some grains of feldspars and quartz, formed by replacement. In some plagioclase grains the replacement has been along the twin planes. Other constituents are orthoclase, andesine, biotite, and quartz.

BENTONITE IN THE STEELE FORMATION

Although major attention was given to the study of Mowry bentonite deposits, observations were made on bentonite beds in the Steele shale. Two places where outcrops present commercial possibilities were examined, namely, a locality near Midwest and another north of Natrona.

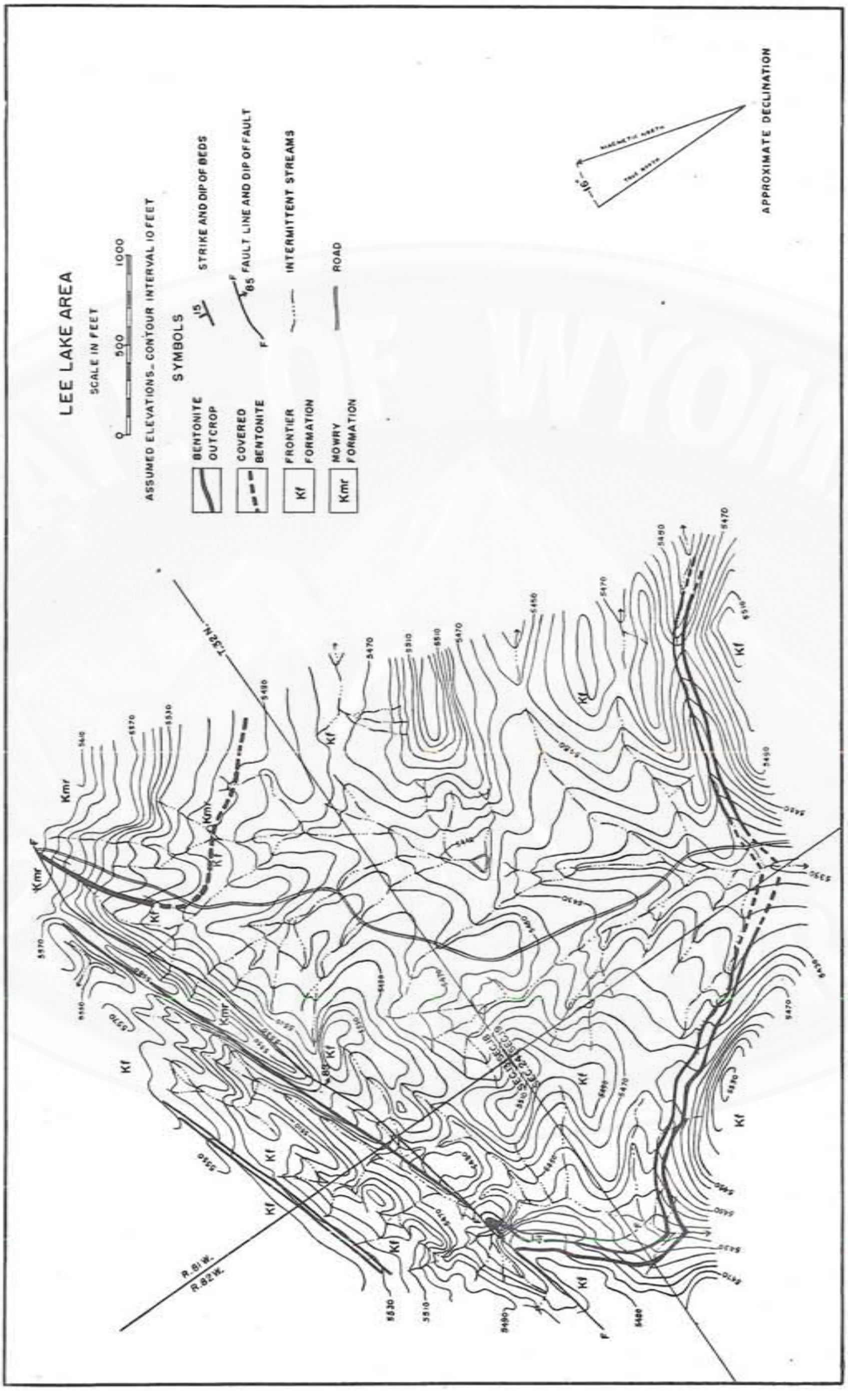

Figure 4. Map of Lee Lake area showing topography and bentonite outcrops.

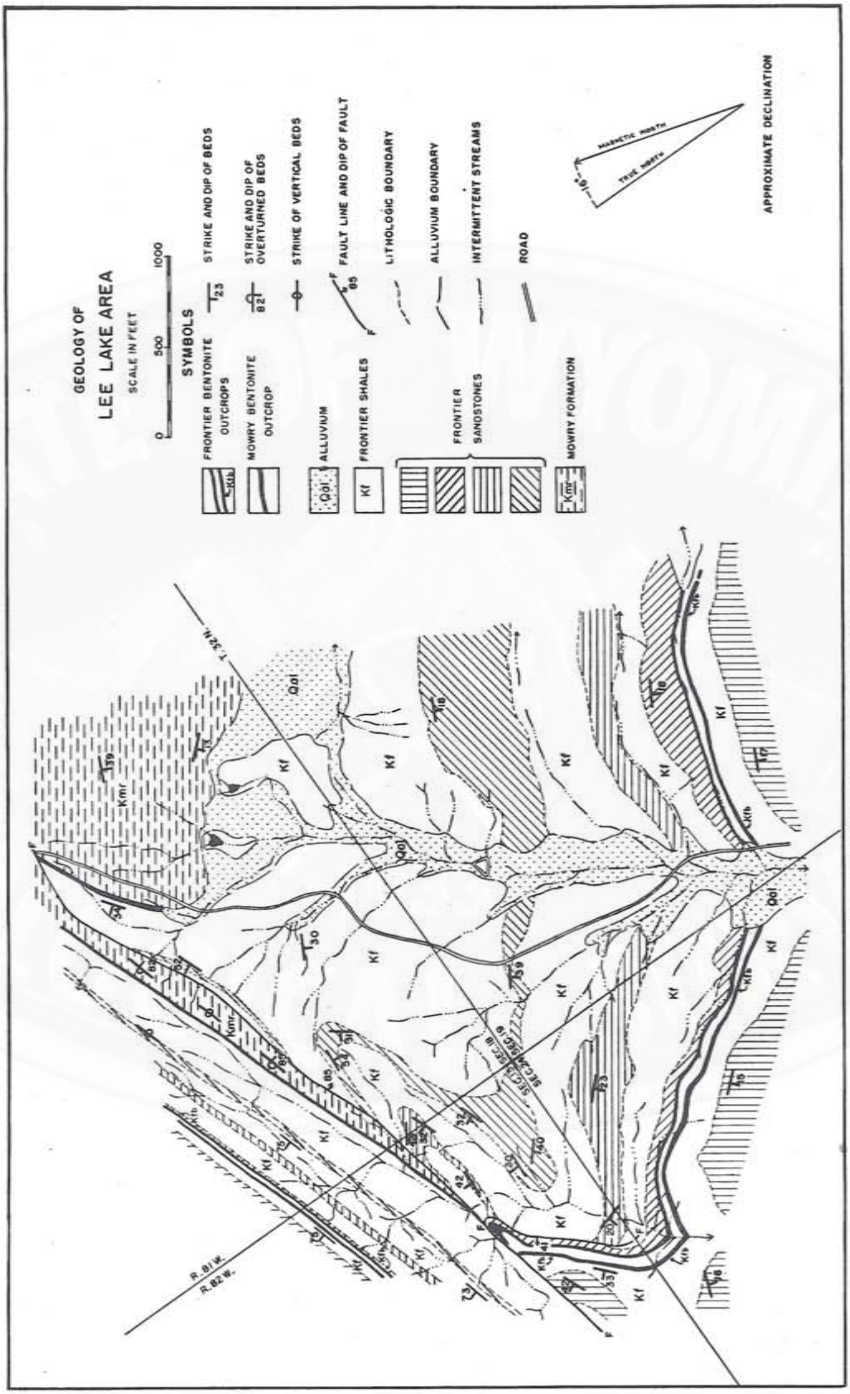

Figure 5. Geological map of the Lee Lake area.

Midwest Area

The bentonite beds noted near Midwest are stratigraphically higher than the Shannon sandstone member of the Steele shale. Heathman (8:15), in describing this locality, gave a thickness of 2,300 feet for the entire formation, and 170 feet for the Shannon sandstone, which lies about 1,000 feet above the base. According to him, a thick bentonite bed is located 300 feet above the Shannon sandstone.

The bed is exposed in the syncline west of Salt Creek anticline, and extends from the northwestern part of T. 39 N., R. 79 W., through the western part of T. 40 N., R. 79 W., to the southwestern part of T. 41 N., R. 79 W. The syncline is shown on the map of Salt Creek oil field in U. S. Geological Survey Professional Paper 163 (18:pl. 6). The same bed is also exposed south of the Salt Creek field, approximately two miles south of Columbine. Heathman gives a thickness of 12 feet for this bed whereas the writer determined it to be 9 feet thick. Here a two-foot bed of bentonite was observed stratigraphically below the main bed, with 11 feet of shale separating the two.

The field characteristics of these beds are as follows: the upper has a great quantity of selenite at its base, and selenite crystals are scattered through the thickness without any orderly distribution. It also includes thin discontinuous layers of black shale. The upper 2 feet is high in shale content and grades upward into true shale. The lower bentonite bed is also rich in selenite.

The nature of both beds may be summarized by saying that they are not uniform in character because of varying selenite and shale content. Both weather into a powdery yellow-brown material. When fresh they are cream-colored and grade into brown where the shale content is greater.

Although the main bed was not followed along its entire length of outcrop, the overburden is fairly thin along most of it, ranging from 1 to 25 feet thick. This fact, together with the low dip, increases the economic possibilities of the deposits.

Steele bentonite from sec. 20, T. 40 N., R. 79 W., examined under the microscope consists of 95 per cent montmorillonite and possibly other clay minerals, and 5 per cent of feldspar, biotite, and glass. Montmorillonite is present as aggregates of fibers thicker and more distinct than in any of the samples previously described. Small areas of finer-grained montmorillonite seem to be entirely replaced grains of other minerals or glass. The nonclay minerals are, in order of abundance, plagioclase, orthoclase, biotite, and a little glass. They are arranged in more or less parallel discontinuous rows. The feldspars are somewhat replaced by montmorillonite and the glass is almost completely replaced.

Natrona Area

North of Natrona, in the SW 1/4 and the N 1/2 sec. 4, and the N 1/2 sec. 3, T. 36 N., R. 83 W., there is another outcrop of Steele bentonite, which in general strikes N. 80° E. and dips 9° S.

Three bentonite beds are exposed here, two thick ones separated by limestone and a thin bed several feet higher in the succession. Of the two thick beds the lower is 5 feet thick and the higher about 4 feet thick. The interbedded limestone is approximately one foot thick. These beds are best exposed in sec. 4. Bentonite is fresh on the surface, and is cream-colored. It has scattered selenite crystals and in some places thin layers of selenite were observed. The overburden is relatively thick over the entire area, and is thickest in sec. 3.

The bentonite, like that in the Midwest area, lies stratigraphically higher than the Shannon sandstone, but the two may not correlate directly because the number of beds is different in both places and because no interbedded limestone was observed near Midwest. Although the matter cannot be proved until more work is done in the areas, it indicates either that there is a lateral variation in the nature of the Steele shale, shown by the different relations of the bentonite beds in both localities, or that the shale contains several bentonite beds and that the ones cropping out at Natrona are not the same as those in the Midwest area.

Steele bentonite from sec. 4 of the Natrona area contains about 95 per cent montmorillonite and probably some kaolin. One lithic fragment consisting of glass and plagioclase was found. It is replaced by montmorillonite on the edges and along the mineral boundaries. Small amounts of carbonate are present and seem to be the result of introduction.

TONNAGE ESTIMATES

The tonnage estimates are approximate and have been calculated from the maps on the basis of a specific gravity of 2.79 for the bentonite. They give the available tonnage of bentonite which is overlain by overburden no thicker than three times that of the thickness of the individual beds. No accurate reserve could be computed for the Bates Park area because the map does not permit making a detailed estimate.

TABLE II

TONNAGE ESTIMATES

Deposit	Short Tons
Emigrant Gap	277,375
Alcova	300,300
Bates Park	Several million
Bates Creek No. 1	224,800
Bates Creek No. 2	264,000
Lee Lake	101,300
Midwest	Not estimated
Natrona	Not estimated

PETROGRAPHIC FEATURES

Representative samples of bentonite from eight of the deposits were studied microscopically and their main characteristics are included under the section on description of deposits. X-ray diffraction study of three of the samples was carried out with a rotating powder camera using copper radiation. The clay-mineral and the nonclay-mineral composition of the bentonites studied are here discussed.

Clay Minerals

It is difficult to tell by microscopic observation alone whether or not montmorillonite is the only clay mineral present. Its very fine-grained texture makes the measurement of optical properties difficult. Only in the slide of Steele bentonite from the Midwest area was it possible to obtain an interference figure. The figure had a negative sign and small 2V, which are optical properties of montmorillonite.

Table III gives the indices of refraction and birefringence of the specimens described above, plus two more, namely, Mowry bentonite, Bates Creek area No. 2, sec. 31, T. 32 N., R. 80 W., and Frontier bentonite, upper bed, Lee Lake area, sec. 13, T. 32 N., R. 82 W. The indices are in general higher than those given for montmorillonite (13:59 and 61). This fact suggests a possible mixture with other clay minerals. It is known, however, that the indices of refraction of montmorillonite vary considerably with water content (19:514), which may be another reason explaining the results obtained since the indices were determined on air-dried samples. The birefringence corresponds with that given for montmorillonite.

TABLE III

INDICES OF REFRACTION OF MONTMORILLONITE

Sample No.	Locality	Formation	Indices of Refraction		Birefringence
			α	γ	
1	Emigrant Gap	Mowry	1.5112	1.5325	0.0213
2	Blue Hill	Mowry	1.5075	1.5287	0.0212
3	Alcova	Mowry	1.5075	1.5275	0.0200
4	Bates Creek No. 1	Mowry	1.5112	1.5325	0.0213
5	Bates Creek No. 2	Mowry	1.5125	1.5325	0.0200
6	Lee Lake Upper bed	Frontier	1.4978	1.5198	0.0220
7	Lee Lake Lower bed	Frontier	1.5100	1.5300	0.0200
8	Bates Park	Mowry	1.5075	1.5300	0.0225
9	Midwest	Steele	1.4951	1.5171	0.0220
10	Natrona	Steele	1.5023	1.5250	0.0227

The X-ray diffraction measurements given in Table IV indicate that montmorillonite is the clay mineral present in the Mowry, Frontier, and Steele bentonites. The pattern for Mowry bentonite has several lines which correspond to lines of nontronite (5). The Frontier bentonite pattern has one line which fits with nontronite.

TABLE IV

X-RAY DIFFRACTION MEASUREMENTS OF BENTONITE

Mowry Bentonite Alcova Area			Frontier Bentonite Lee Lake Area			Steele Bentonite Natrona Area		
A.U.	Int.	Min.	A.U.	Int.	Min.	A.U.	Int.	Min.
11.10	v.s.	M	11.44	s	M	11.21	s	M
4.46	s	M	4.44	s	M	4.46	v.s.	M
4.23	m	Q	4.22	w	Q	4.03	s	C
3.33	v.s.	Q	3.31	v.s.	Q	3.12	w	C
2.53	m	M	2.53	w	M	2.53	w	M
2.43	w	N	2.43	w	N			
2.25	m	M						
2.203	v.w.	N						
2.112	w	N?				2.194	v.w.?	C?
1.958	w	N						
1.805	m	Q	1.808	w	Q			
1.653	w	M	1.630	v.w.	M	1.680	v.w.	M
1.529	m	Q				1.567	v.w.	C
1.488		M	1.488	w	M	1.489	w	M
1.384	m	Q	1.370	w	Q	1.423	v.w.	C
1.281	v.w.	M	1.269	v.w.	M			
1.248	v.w.	M						

Measurements were compared with those given by Hagner (6) and Gruner (5).

A.U.—Interplaner spacing in Ångstrom units.
Int.—Intensity
Min.—Mineral
v.s.—Very strong, s—Strong, m—Medium, w—Weak, v.w.—Very weak
M—Lines corresponding to montmorillonite
N—Lines corresponding to nontronite
Q—Lines corresponding to quartz
C—Lines corresponding to cristobalite

In general, it can be stated that the most abundant clay mineral in the bentonites studied is montmorillonite and that Mowry bentonite from the Alcova area has nontronite also.

Nonclay Minerals

Nonclay minerals include all those present in bentonite other than the clay minerals.

In the specimens of Mowry bentonite the following nonclay minerals were found: orthoclase, plagioclase, biotite, quartz, zircon, and magnetite, and also glass particles. The same minerals, with the exception of zircon and magnetite, were found in the Frontier and Steele bentonites.

These minerals occur mostly as angular grains which, for the Mowry bentonite, have an average diameter of 0.1 to 0.2 mm. The largest ones are 0.3 mm. in diameter. The Steele and Frontier bentonites have less nonclay minerals and the grains are smaller.

The feldspars are the most abundant nonclay mineral grains. Where the plagioclase could be determined it was andesine. The feldspars show alteration and replacement effects already described. Biotite is present in irregular flakes somewhat altered. Muscovite was observed in only one specimen and was highly replaced by clay minerals. Quartz in general occurs in small amounts, is usually angular, and in some specimens is partially replaced by clay minerals. The X-ray patterns indicate that quartz is present in all the specimens studied. Zircon is present in small grains, some of which are euhedral. Magnetite was found in very small amounts and is altered to hydrous iron oxide, probably limonite. Glass particles are very scarce and when present are highly altered.

Cristobalite has been reported by Gruner (4) as present in considerable amount in bentonite from near Casper. It was not possible to determine its presence in the samples observed microscopically, but the Steele bentonite that was X-rayed has several lines in its pattern which correspond with those of cristobalite.

Another observation of importance is that the selenite crystals, apparently so abundant in hand specimen, are very scarce in thin sections. From field and microscopic evidence the writer believes that selenite formed later than the clay minerals as a diagenetic product. In the field it occurs mostly along cracks and bedding planes, being most abundant in the weathered portions of the outcrops. The scarcity of selenite in thin sections is due to the fact that pure material was used in making the slides.

Structures

The structure of bentonite varies from massive to laminated. Under the microscope some specimens are massive, others show a rough arrangement of the nonclay-mineral grains in rows, and some show subparallel arrangement of montmorillonite flakes and of rows of nonclay minerals. Alignment is parallel to the bedding of the rock. The original fragmental structure of the volcanic ash has been retained in most of the bentonite specimens.

PHYSICAL PROPERTIES

Table IV gives the physical properties of bentonite samples collected in the Casper area. Results obtained on a sample of typical Black Hills bentonite are included for comparison. The tests were made by the University of Wyoming Natural Resources Research Institute, under the direction of Dr. Henry G. Fisk. The details of testing methods used on all samples, including the standard, are identical. All results, therefore, may be compared directly with those obtained on the standard sample.

The column for per cent retained on 200-mesh indicates the percentage of the sample retained on a 200-mesh screen as ground for testing. The per cent grit column gives the percentage of the sample retained on a 325-mesh screen after the sample had been hydrated, or suspended in water, and screened wet. The per cent colloidal material column gives the percentage of the sample remaining in colloidal suspension for 18 hours. The Stormer viscosity column gives the viscosity, in centipoises, of a 6% suspension. Gel strengths were determined by the Stormer viscosimeter and are given in grams. Wall building properties were determined with a test unit constructed in the University of Wyoming Natural Resources Research Institute laboratory similar to the Baroid low pressure wall-building tester. Water loss is given in cubic centimeters. The compressive strengths and dry compressive strengths, pertaining to the sand-binding properties, were determined according to standards of the American Foundrymen's Association, using 4 per cent bentonite by weight based on total weight of the batch. Strengths are given in pounds per square inch.

The tests indicate that the bentonites of the Casper area are generally deficient in colloidal material and this deficiency is emphasized by the results on gel strength and viscosity. The sand-binding properties of some samples indicate better suitability for that purpose than for uses in which colloidal properties are more important.

TABLE V

PHYSICAL QUALITIES OF BENTONITE FROM THE CASPER AREA

Sample	Dry Color	Per Cent Retained on 200-mesh	Per Cent Grit 325-mesh	Per Cent Colloidal Material	Stormer Viscosity (centipoises)	GEL STRENGTH (in grams)		WALL-BUILDING PROPERTIES		SAND-BINDING PROPERTIES (pounds per square inch)	
						Initial	10 Min.	Water Loss (in cc.)	Cake Thickness	Green Com-pressive Strength	Dry Com-pressive Strength
Standard Black Hills	Cream	5.5	2.20	96	16.0	26.00	35.00	18	3/32″	8.24	85.5
1.	Light-gray	4.0	.12	57	3.2	5.08	5.08	44	7/64″	4.84	72.9
2.	Cream	7.0	2.80	47	4.3	5.58	8.58	37	3/32″	7.74	40.8
3.	Light-gray	8.0	.10	59	4.0	4.58	8.58	29	3/32″	7.56	65.7

TABLE V.—CONTINUED

4.	Gray	8.0	.70	51	2.7	4.58	5.58	100	5/32"	8.06	69.9
5.	Light-gray	4.0	.25	59	6.0	5.08	5.08	23	4/32"	5.32	82.9
6.	Gray	6.0	.50	65	3.2	6.58	....	46	5/64"	7.87	57.9
7.	Light-gray	3.5	1.32	79	5.0	7.58	10.58	26	5/64"	5.49	73.3
8.	Light-gray	8.0	3.90	43	3.2	5.58	....	38.5	5/64"	5.20	74.0
9.	Cream	3.0	2.20	72	5.7	5.58	....	20	5/64"	8.56	61.1
10.	Yellow-ish	4.0	.20	87	4.5	5.08	6.08	35	4/32"	12.80	43.2

SAMPLE LOCALITIES: (1) Mowry bentonite, Emigrant Gap area, sec. 9, T. 33 N., R. 81 W. (2) Mowry bentonite, Blue Hill deposit, Emigrant Gap area, sec. 31, T. 33 N., R. 80 W. (3) Mowry bentonite, Alcova area, sec. 36, T. 30 N., R. 83 W. (4) Mowry bentonite, Bates Creek area No. 1, sec. 10, T. 31 N., R. 80 W. (5) Mowry bentonite, Bates Creek area No. 2, sec. 31, T. 32 N., R. 80 W. (6) Upper Frontier bentonite, Lee Lake area, sec. 13, T. 32 N., R. 82 W. (7) Lower Frontier bentonite, Lee Lake area, sec. 13, T. 32 N., R. 82 W. (8) Mowry bentonite, Bates Park area, sec. 10, T. 30 N., R. 81 W. (9) Steele bentonite, Midwest area, sec. 20, T. 40 N., R. 79 W. (10) Steele bentonite, Natrona area, sec. 4, T. 36 N., R. 83 W.

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